

On the absence of nova shells

L. Schmidtobreick¹, M. Shara², C. Tappert³, A. Bayo^{3,4}, A. Ederoclite⁵

¹ *European Southern Observatory, Casilla 19001, Santiago 19, Chile*

² *Department of Astrophysics, American Museum of Natural History, Central Park West and 79th Street, NY 10024-5192, USA*

³ *Instituto de Física y Astronomía, Universidad de Valparaíso, Avda. Gran Bretaña 1111, Valparaíso, Chile*

⁴ *Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany*

⁵ *Centro de Estudios de Física del Cosmos de Aragón, Plaza San Juan 1, Planta 2, Teruel, E44001, Spain*

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ABSTRACT

We present our wide field $H\alpha + N[II]$ observations of 15 cataclysmic variables to search for remnant nova shells. Such shells have been found around other cataclysmic variables that were hitherto not known as novae. Our candidates were selected as objects in the period regime of high-mass transfer systems that experience - at least occasionally - low mass transfer rates. The fact that we find no indication of a nova shell in any of these systems allows us to set a lower limit of 13000 years to the recurrence time of these objects.

Key words: stars: novae, cataclysmic variables

1 INTRODUCTION

A nova eruption in a cataclysmic variable (CV) is a thermonuclear explosion on the surface of the white-dwarf primary once it has accreted a critical mass from its late-type companion. During the nova eruption, material is ejected into the interstellar medium, forming an expanding shell around the CV which can be observed once its angular size is sufficiently large to be resolvable from the inner binary (see e.g. Gill & O’Brien 1998). The total ejected mass is estimated between 10^{-6} and $10^{-4} M_{\odot}$ (Bode & Evans 2008, other references therein).

In-between nova eruptions the binary is supposed to appear as a “normal” CV, i.e. its behaviour is dominated by its current mass-transfer rate and the magnetic field strength of the white dwarf (Vogt 1989). However, the model of Shara et al. (1986) predicts that the nova eruption strongly affects the mass-transfer rate \dot{M} . After an initial phase of enhanced \dot{M} due to the irradiation of the secondary star by the eruption-heated white dwarf (Kovetz et al. 1988), \dot{M} is supposed to decline over the next centuries by several orders of magnitude (Livio & Shara 1987), possibly even to the point that $\dot{M} \sim 0$ due to the secondary star losing contact to its Roche lobe, a scenario that has been termed “hibernation”. The recent discovery of ancient nova shells around two low-mass transfer systems, i.e. Z Cam (Shara et al. 2007) and AT Cnc (Shara et al. 2012) provides strong support for the idea of the nova - dwarf nova cycle originally proposed by Vogt (1982). However, even the existence of dwarf novae that have experienced nova outbursts in the past does not prove the hibernation model. Individual such cases could equally

be explained by the fact that all CVs can explode as a nova once sufficient material has been accumulated on the surface of the white dwarf. Only a careful population study of novae in comparison to high- and low-mass transfer systems can yield the answer to this long-debated question.

Most observed old novae do actually show a very high mass transfer rate (see e.g. Schmidtobreick et al. 2005; Tappert et al. 2012, 2014). This is expected as the recurrence time, i.e. the time between two nova outbursts, is supposed to be smaller for high mass transfer systems and so they are more likely to be observed during a nova eruption. Still, this also means that most of the observed old novae are not in ‘hibernation’ which could be due to the time-scales and the relatively short time that has passed after the nova eruption (less than 100 years in most cases).

The currently known period distribution of novae shows a significant peak at 3–4 h (Tappert et al. 2013a) in rough agreement with the theoretical calculations by Townsley & Bildsten (2005). If one considers all types of CVs, this range between 3 and 4 h is dominated by systems with very high \dot{M} (Townsley & Gänsicke 2009; Schmidtobreick 2013; Rodríguez-Gil et al. 2007). However, there does exist a small population of dwarf novae in this period range (Ritter & Kolb 2003). Also three old novae that have been re-discovered only recently (Schmidtobreick et al. 2005; Tappert et al. 2012) present optical spectra that are much more akin to dwarf nova spectra than to nova-like stars. At least one of them shows also evidence for dwarf-nova like outburst behaviour (V728 Sco; Tappert et al. 2013b). Could the presence of low \dot{M} CVs in this range be a consequence of a previous nova eruption as predicted by

Table 1. Summary of the observational details: Object, Filter, Date & UT of the first exposure, the number of exposures, the total exposure time, the CV subtype (Ritter & Kolb 2003), the orbital period, and the distance. The references for P_{orb} and d are given below.

Object	Filter	Date	UT	#	T_{exp} [s]	Type	P_{orb} [d]	d [pc]
2MASS J07465548-0934305	H α	2014-03-16	01:13	7	5398	DN?	0.1416 (1)	180 (1)
	H α	2013-12-13	04:41	7	5398			
	R	2014-03-16	02:55	7	804			
	R	2013-12-13	06:23	7	804			
EF Tuc	H α	2013-12-12	00:40	7	5389	DN	0.15 (2)	346 (16)
	R	2013-12-12	02:23	7	804			
TU Men	H α	2014-03-15	00:16	7	5389	DN	0.1172 (3)	210 (17)
	H α	2013-12-12	02:54	7	5389			
	R	2014-03-15	02:05	7	804			
	R	2014-12-12	04:36	7	804			
2MASS J09400257+2749420	H α	2014-03-15	02:42	7	5389	DN	0.16352 (4)	
	R	2014-03-15	04:25	7	804			
SDSS J075939.78+191417.2	H α			7	5389	DN	0.130934 (5)	
	R	2014-03-17	01:49	7	804			
CTCV J1226-2527	H α	2014-03-15	05:22	6	4620	DN?	0.1544 (6)	
		2014-03-16	05:31	7	5389			
	R	2014-03-15	06:34	7	804			
	R	2014-03-16	07:12	7	804			
VZ Sex	H α	2014-03-17	02:17	9	6929	DN	0.1487 (7)	433 (18)
	R	2014-03-17	03:58	9	1034			
KW2003 105	H α	2014-03-15	09:21	2	855	DN?	0.1170 (8)	134 (19)
	H α	2014-03-16	08:09	7	5389			
	R	2014-03-16	09:22	7	804			
	H α	2014-03-17	01:13	7	5389			
BF Ara	R	2014-03-17	05:10	14	1609	DN	0.08418 (9)	758 (19)
	H α	2014-03-16	03:22	7	5389			
X Leo	R	2014-03-16	05:04	7	804	DN	0.1644 (10)	322 (19)
	H α	2014-03-25	07:35	7	5389			
GS Pav	R	2014-03-25	09:27	7	804	VY Scl	0.155270 (11)	405 (19)
	H α	2013-12-14	03:19	7	5389			
Tau-2	R	2013-12-14	05:01	7	804	VY Scl	0.1495 (12)	787 (19)
	H α	2013-12-07	01:00	7	5389			
TT Ari	R	2013-12-07	03:05	7	804	VY Scl	0.13755 (13)	335 (20)
	H α	2013-12-13	02:04	7	5389			
VZ Scl	R	2013-12-13	03:46	7	804	VY Scl	0.144622 (14)	474 (19)
	H α	2013-12-14	05:31	7	5389			
1RXS J075330.1+044606	R	2013-12-14	07:12	7	804	VY Scl	0.133 (15)	

(1)Pretorius & Knigge (2008); (2)Ritter & Kolb (2003); (3)Mennickent (1995); (4)Krajci & Wils (2010); (5)Drake et al. (2010); (6)Augustejn et al. (2010); (7)Thorstensen et al. (2010); (8)Woudt et al. (2005); (9)Olech et al. (2007); (10)Shafter & Harkness (1986); (11)Groot et al. (1998); (12)Thorstensen & Taylor (2001); (13)Wu et al. (2002); (14)Warner & Thackeray (1975); (15)Sokolovsky et al. (2012); (16)Pretorius & Knigge (2012); (17)Sion et al. (2008); (18)Mennickent et al. (2002); (19)Ak et al. (2008); (20)Gänsicke et al. (1999)

the hibernation model? We here present a photometric survey with an H α narrow-band filter to search for nova shells around CVs in the 3–4 h period range with low \dot{M} (dwarf novae) or that show occasional low states (VY Scl stars). The discovery of such nova shells would provide strong evidence for previous nova eruptions being the cause for the presence of CVs with relatively low \dot{M} in the 3–4 h period range.

2 DATA AND IMAGE PROCESSING

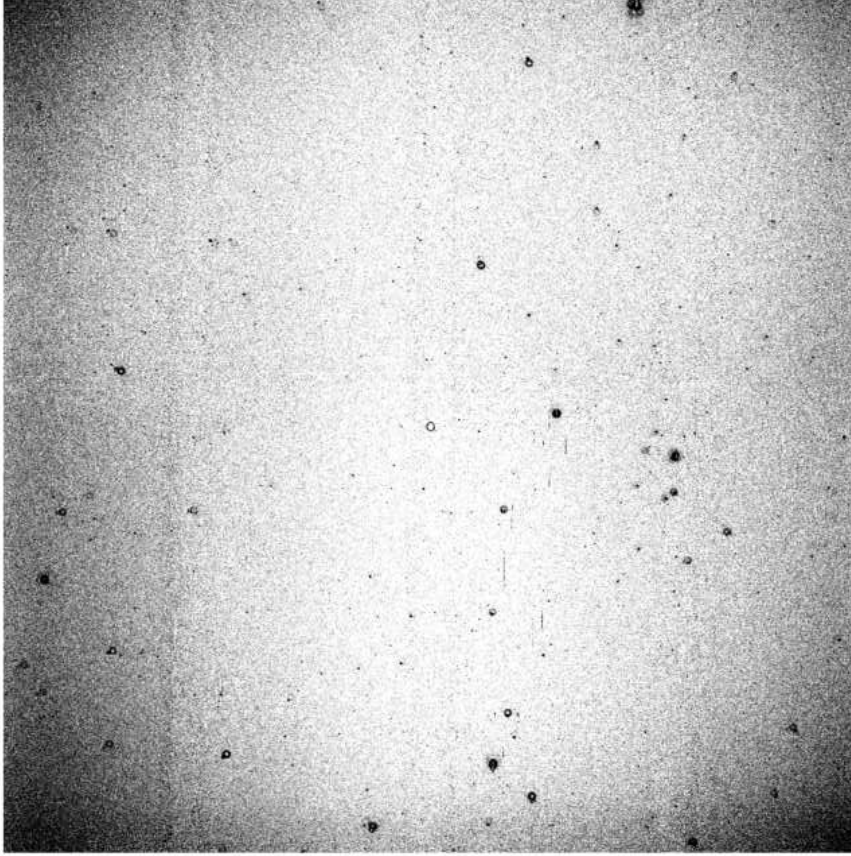
We used the Wide Field Imager (Baade et al. 1999) at the Cassegrain focus of the 2.2-m MPG telescope at La Silla, Chile to take deep H α + [NII] images of a 30 arcmin region around the selected CVs. In general, seven pointings with

small dither offsets to account for the gaps between the chips were observed. R images were taken to subtract the continuum. A summary of the data taken for all objects is given in Table 1.

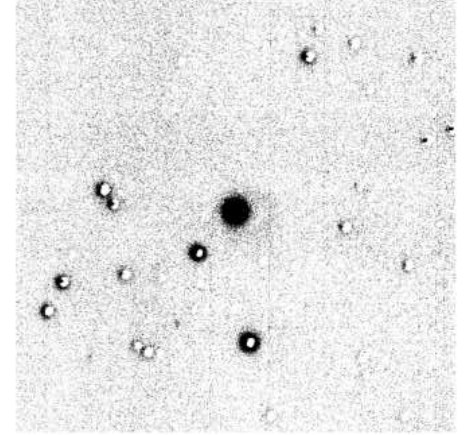
The data reduction was done with THELI (Schirmer 2013; Erben et al. 2005), including standard bias, overscan, and flat correction. The astrometry was calculated with about 50–200 stars for each chip, allowing for a polynomial of order 3 to fit the distortion. For all fields, the internal error was $< 0.01''$ while the match with the PPMXL catalogue yielded an accuracy of $\approx 0.31''$ which is consistent with the accuracy of the catalogue positions.

To correct for sky variations between exposures that would show in the mosaic, a constant sky value was calculated for each exposure and subtracted from each chip. Then, the average sky value from all exposures of a field

SDSS J075939.78+191417.2



2MASS J07465548-0934305



GS Pav

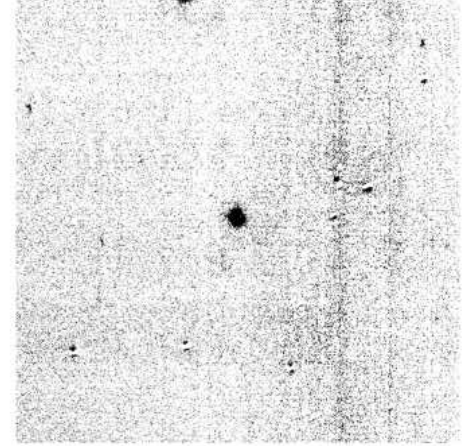


Figure 1. As examples for the resulting net mosaic images ($H\alpha + [NII]$ minus R) we show a $30' \times 30'$ mosaic of the field around SDSS J075939.78+191417.2 on the left side and $2' \times 2'$ zooms onto 2MASS J07465548-0934305 and GS Pav on the right side. The contrast has been set to $\pm 2\%$ of the sky background.

were added. The individual chips of all exposures of one field were combined into the mosaic for each filter. In the end, the mode of data values was used to scale the R-mosaic with respect to the narrowband mosaic to be then subtracted as continuum. The resulting mosaic images were inspected by eye to search for nova shells.

3 RESULTS

Our main result is that no shell is found in any of the analysed fields. Some examples for the created net ($H\alpha + [NII]$ minus R) mosaic images are given in Figure 1. We used ESO's Exposure Time Calculator and compared the results with the S/N of the average sky to estimate an upper limit for our non-detections. With our sensitivity, we would have easily ($S/N = 3$ per arcsec²) detected signals as low as $2.5 \times 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ arcsec}^{-2}$ and we expect from previous detections (Shara et al. 2007, 2012) that ancient nova shells are a factor 5 brighter than this limit.

4 DISCUSSION

From our field of view as well as the resolution and seeing conditions, we estimate that we should have detected any shell with a diameter between about 3 arcsec and 30 arcmin. For objects that are between 200 pc and 1 kpc we would thus detect any shell with a diameter between 0.02 and 2 pc. Note that we might detect more if the relation between size and distance are advantageous, but for the size between 0.02 and 2 pc, we are complete. In general, for the inner, denser parts of shells, velocities between 300 and 500 km/s have been found with a few exception of much higher velocities (see e.g. Shara et al. 2012; Downes & Duerbeck 2000; Gill & O'Brien 1998, others herein). For these kind of shells, the detection limit due to the size of the detector and the resolution converts into an age limit of the nova eruption which is between 50 and 2000 years. We know from previous observations (Shara et al. 2007) that the nova shells can be visible for these 2000 years, while a nova eruption younger

than 50 years should have been observed directly in any of these systems.

However, not all novae form shells. In fact, Cohen (1985) observed 17 old novae, chosen as the brightest and closest known, and found 8 shells corresponding to a success rate of about 47%. Gill & O'Brien (1998) observed 17 random novae without known shell and found 4 shells yielding a success percentage of 24. The most complete study was executed by Downes & Duerbeck (2000) who observed 30 novae and found 13 shells which yields again a success rate of 47%. For novae that are further away a better resolution is needed to find the shells. So only nearby novae can give an unbiased success percentage. Alternately, one can use HST imagery as shown by Downes & Duerbeck (2000). We thus ignore the low success rate of Gill & O'Brien (1998) as their data set is most likely biased with unresolved shells and adopt the value of 47% as the percentage of novae that form a shell. This value agrees with the complete study of Downes & Duerbeck (2000) as well as the one of Cohen (1985) for near novae.

Assuming that all 15 of our observed CVs had a nova eruption during the last 2000 years, we should thus have found 7 nova shells on average. The fact that we find none is thus a strong indication that any nova eruption happened much further in the past than we had assumed when starting this project. For an average recurrence time t_{rec} , we derive the individual probability $p = 0.47 \times \Delta t \times t_{\text{rec}}^{-1}$ for a nova to explode and produce an observable shell within the time interval Δt . From this, we compute the probability that none of the novae in our sample shows a shell. We can rule out that any nova explosion happened during the last 5000 years with a 3-sigma confidence level and push this value to 13000 years with a 1-sigma confidence level. This value can thus be regarded as a lower limit for the average outburst recurrence time.

These findings are consistent with the interval that can be derived from the average mass transfer rate of these CVs. Depending on the mass of the white dwarf as well as its core temperature, the accreted mass M_{ign} has to be of the order of $10^{-5}M_{\odot}$ to $10^{-4}M_{\odot}$ to allow the ignition of the nova explosion (Townesley & Bildsten 2005). Townesley & Gänsicke (2009) find that the average mass transfer rate for CVs in the 3-4 h period range that are not SW Sex stars is about $5 \times 10^{-10} M_{\odot}/\text{y}$. The white dwarf in these systems thus needs to accrete for at least 20.000 years to reach the critical M_{ign} needed for the nova explosion.

In a study of the parameter space for nova outbursts (Yaron et al. 2005), also more extreme cases of novae are discussed. For very massive white dwarfs ($M_{\text{WD}} \approx 1.4M_{\odot}$), they find that only small amounts of accreted material $m_{\text{acc}} \approx 5 \cdot 10^{-8}$ are necessary to ignite the nova. This seems to be in contradiction to our findings, as this material should be accreted in the order of 100 years. However, according to their models, these kind of novae eject a very small amount of material, so might not be the ones that form shells in the first place. Also, such high white dwarf masses are rather rare, so the probability that any such system is among our sample is very low.

The fact that we do not find any nova shells, also means that, contrary to our initial assumptions, the presence of low mass transfer rate systems in the period regime of the SW Sex stars cannot necessarily be explained by a modification of the mass transfer rate due to a recent nova explosion.

A larger sample of such stars needs to be analysed to decide with a high level of confidence whether these low mass transfer systems actually follow the expected outburst behaviour or not.

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